Effect of cooling rate and oxygen fugacity on the crystallization of the Queen Alexandra Range 94201 martian melt composition

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Introduction: Although many basaltic shergottites have been recently found in north African deserts, QUE94201 basaltic shergottite (QUE) is still important because of its particular mineralogical and petrological features. This meteorite is thought to represent its parent melt composition [1-3] and to crystallize under most reduced condition in this group [1,4]. We performed experimental study by using the synthetic glass that has the same composition as the bulk of QUE. After homogenization for 48 hours at 1300°C, isothermal and cooling experiments were done under various conditions (e.g. temperature, cooling rates, and redox states). Our goals are (1) to verify that QUE really represents its parent melt composition, (2) to estimate a cooling rate of this meteorite, (3) to clarify the crystallization sequences of present minerals, and (4) to verify that this meteorite really crystallized under reduced condition.

Isothermal experiments under IW+1: Fig. 1 shows the pyroxene composition that crystallized at various temperatures. Pyroxene composition shows good agreements with the zoning pattern of pyroxene in natural QUE. Especially, the core compositions of synthetic pyroxenes are close to those of QUE. Furthermore, minor elements (Al and Ti) are similar to QUE, but quite different from Shergotty and Zagami. These results indicate that the bulk composition of QUE is nearly identical to its parent magma composition. Further discussion is seen in the abstract by McKay et al. [5] somewhere in the same volume.

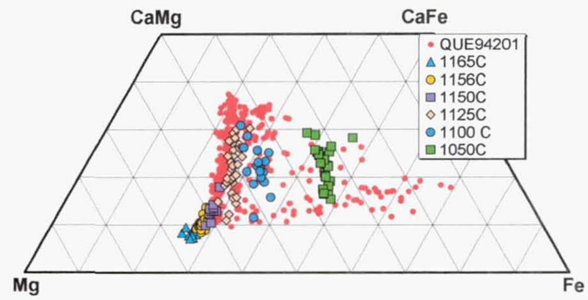

Fig. 1. Pyroxene composition from isothermal experiments under IW+1.

Cooling experiments under IW+1: Cooling experiments were done at cooling rates of 20, 10, 5, 1, 0.7, and 0.5°C/hr from just above the liquidus temperature (1175°C) to 900°C. Fig.2 is the BSE image of pyroxene from the 0.5°C/hr cooling experiment. As this image shows, the simple single-cooling process could reproduce the same zoning pattern that can be seen in natural QUE pyroxene, that is Mg-rich pigeonite core, mantled augite, and Fe-rich pigeonite rim. Fig. 3 shows pyroxene quadrilaterals of pyroxenes from 5 °C /hr and 0.5 °C/hr cooling experiments quenched at 900 °C, along with natural QUE pyroxene composition. Although both experiments have similar zoning sequence to that in natural QUE, the synthetic pyroxene from the 0.5 °C/hr cooling have the better matches with natural QUE in the absence of Ca-Fe-rich pyroxene. Also, Al and Ti contents of pyroxenes become

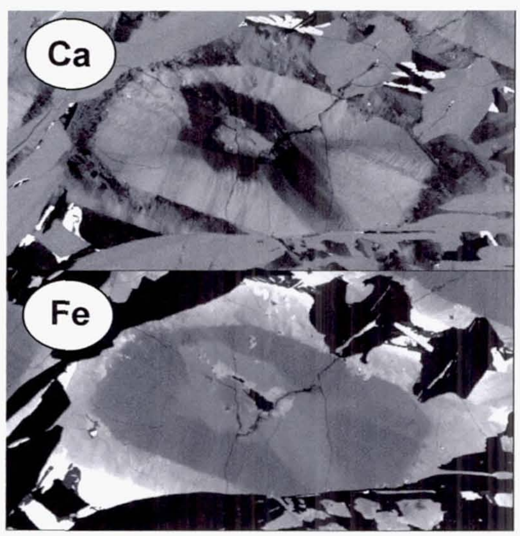

Fig. 2. Ca and Fe maps of the run product from 0.5°C/hr cooling experiment under IW+1.

smaller in slower cooling rate experiments, and both contents in the QUE pyroxene is slightly lower than our slowest cooling rate, 0.5°C/hr. By these reasons, QUE crystallized at the cooling rate between 0.5°C/day [2] and 0.5°C/hr. We also performed 0.5°C/hr and 1°C/hr cooling experiments were quenched at various temperatures. Fig. 4 shows the major elemental composition from 0.5°C/hr cooling runs. It is noted that plagioclase started to crystallize between 1090°C and 1085°C. Run products quenched above 1090°C, which are experiments without plagioclase, have only Mg-rich pigeonite and augite. In contrast, experiments with plagioclase have Fe-rich pyroxenes. Fig 5 is the Al/Ti ratio of these experiments. Experiments with plagioclase have some plots in the area between the lines of 4/1 and 2/1 although all plots derived from experiments without plagioclase stay above the 4/1 line. These results show that the onset of plagioclase crystallization has the relation to the compositional change from Mg-rich to Fe-rich in pyroxenes, and to the abrupt change of Al/Ti ratio. Fig. 6 clearly shows these relations. The Mg/Fe and Al/Ti ratios of pyroxene adjacent to the plagioclase are less or equal to those of the pyroxene core.

Effect of oxygen fugacity: To compare the effects of oxygen fugacity, some isothermal experiments were done under various oxygen fugacities at 1150 °C and 1160 °C. Phase assemblage from these experiments (Table 1) show that olivine crystallized in all runs at QFM-2.0 and above at 1150 °C. Also, under QFM-2.0, pyroxene coexists with olivine, and under IW+1, only pyroxene crystallized at 1150 °C. Therefore QUE seems to have crystallized under IW+1 or more reduced condition because QUE has no olivine except fayalite as late-stage phase and this result is consistent with [1] and [4]. Cooling run was also done under QFM. This run product contains olivine, pyroxene, plagioclase, and opaque minerals. Olivine zoned from Fa_{43} to Fa_{71} and pyroxene is also zoned. Pyroxene compositions from this experiment are quite different from those of QUE and synthetic pyroxene that crystallized under reduced condition (Fig. 8). They are closer

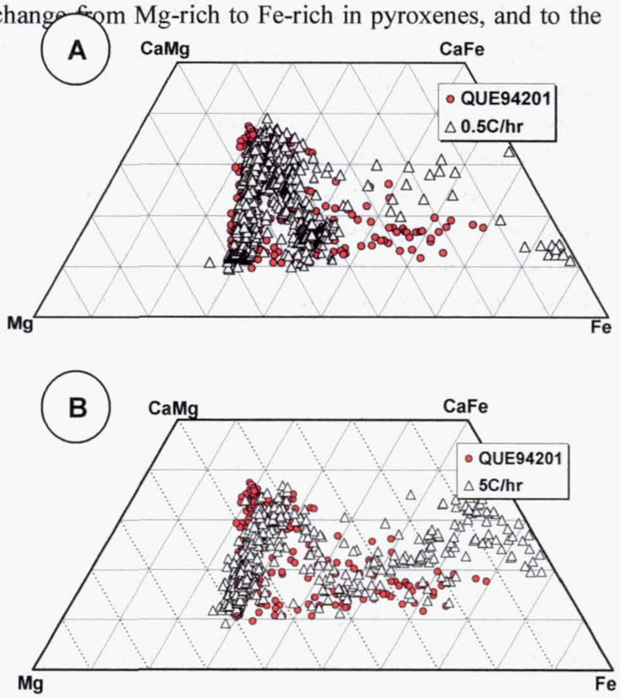

Fig. 3, Pyroxene quadrilaterals of pyroxenes from (A) 0.5 °C/hr and (B) 5 °C/hr cooling experiments quenched at 900 °C with those from QUE94201

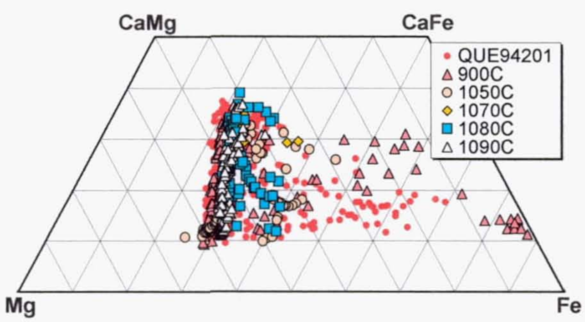

Fig. 4. Pyroxene quadrilateral of pyroxene from 0.5°C/hr cooling experiments quenched at various temperatures.

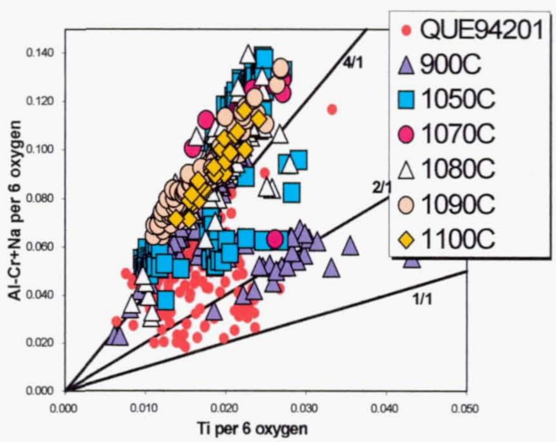

Fig. 5 Al/Ti ratio of pyroxene from 0.5°C/hr cooling experiments quenched at various temperatures.

to those of nakhlites, although the contents of minor elements are different (e.g. Al content of synthetic pyroxene from this cooling experiment is higher than those of nakhlites pyroxene.)

Conclusion: According to these series of crystallization experiments, we have obtained the following conclusions. (1) The bulk composition of QUE is the same or very close to the composition of its parent melt. (2) Simple single-cooling history could reproduce the zoning pattern that is seen in natural QUE. (3) Slower cooling than 0.5°C/hr would produce more similar analogue of QUE in texture and chemical composition. Furthermore, by the contents of minor element of synthetic pyroxene from cooling experiments, QUE is thought to have cooled slower than 0.5°C/hr. (4) Plagioclase began to crystallize after the end of Mg-rich pyroxene crystallization, and at the same time of Fe-rich pigeonite rim crystallization. (5) The abrupt change of Al/Ti ratio of pyroxene can serve as a good marker of the onset of plagioclase crystallization. (6) QUE crystallized under the IW+1 or more reduced condition because olivine crystallized from the bulk composition of QUE under oxidized condition although natural QUE does not contain olivine. (7) Pyroxene from the cooling experiment under QFM is augite that is different from those of QUE, and is similar to nakhlites pyroxene in major element composition.

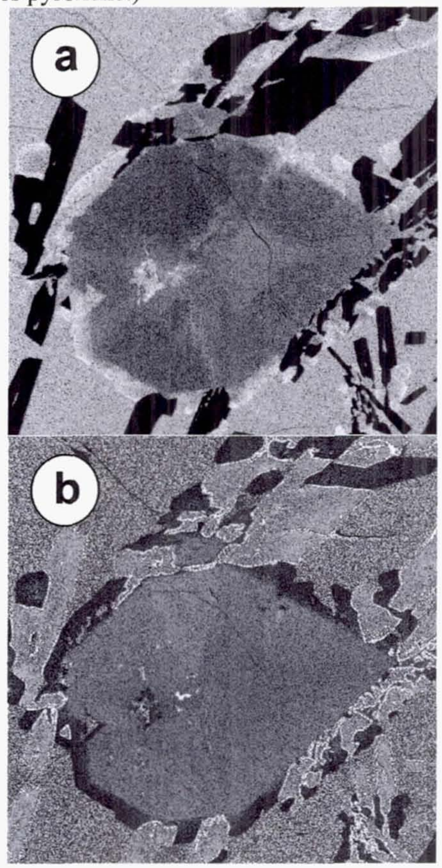

Fig. 6. (a) Fe/Mg and (b) Al/Ti maps of pyroxene grain from 1°C/hr cooling experiment under IW+1 quenched at 1050 °C.

References: [1] McSween H. Y. et al. (1996) *GCA, 60*,4563-4570. [2] Mikouchi T. et al. (1998) *Meteorit. Planet. Sci., 33*, 181-189. [3] Wadhwa M. et al. (1998) *Meteorit. Planet. Sci., 33*, 321-328. [4] Wadhwa M. (2001) *Science, 291*, 1527-1530. [5] McKay et al. (2002) Antarctic Meteorites, *XXVII*, (in this volume).

Table 1. Phase assemblages under various fO_2 at 1050°C and 1060°C.

log fO_2	*1150°C*	*1160°C*
QFM	*Glass, Olivine, Spinel*	*Glass*
QFM-0.5	*Glass, Olivine, Spinel*	*Glass*
QFM-1.0	*Glass, Olivine, Spinel*	*Glass*
QFM-1.5	*Glass, Olivine, Spinel*	*Glass*
QFM-2.0	*Glass, Olivine Pyroxene, Spinel*	*Glass, Pyroxene*
IW+1.0 (QFM-2.5)	*Glass, Pyroxene*	*Glass, Pyroxene*

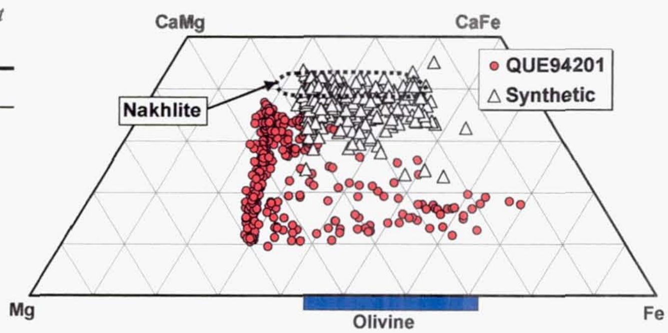

Fig. 7. Pyroxene quadrilateral of pyroxene from 1°C/hr cooling experiments under QFM quenched at 950°C.